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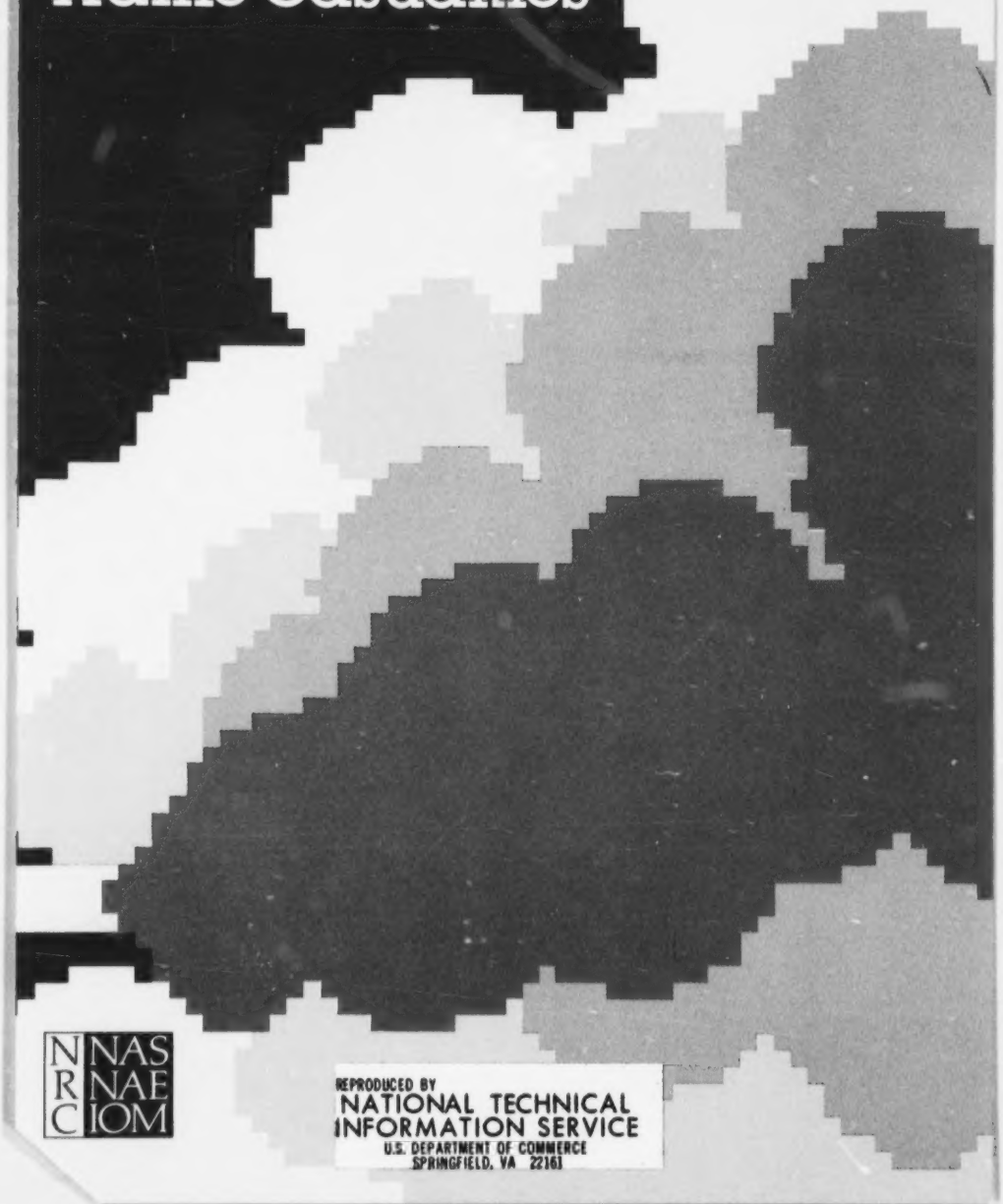

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Impacts of Diesel-Powered Light-Duty Vehicles

Diesel Car Regulation and Traffic Casualties

Report to the

Diesel Impacts Study Committee

Assembly of Engineering

National Research Council

By

Roy McDonald
ARC Technologies, Inc.
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The World Bank

National Academy Press
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PREFACE

In May 1979 the National Research Council began a comprehensive study of the human health effects and public policy issues associated with the prospective increase in the use of diesel-powered light-duty vehicles in the United States. The study was requested by the White House Office of Science and Technology Policy and supported by the U.S. Environmental Protection Agency, the U.S. Department of Energy, and the U.S. Department of Transportation.

The purpose of the study was to inform those government bodies, along with the U.S. Congress, the automotive industry, and the American public, about the current state of knowledge and understanding of diesel engine emissions and their control and to provide an authoritative and balanced examination of the risks and implications of the anticipated growth in the number of lightweight diesel vehicles. According to the projections of the nation's largest automobile manufacturer, General Motors, diesel engines are likely to power some 18 percent of the passenger cars, vans, and small trucks it produces in the year 1985 and as much as 25 percent by the end of the century. All things considered, government authorities responsible for regulations to protect the health and safety of the public need the best scientific, technical, and economic data and analyses on which to base their policy decisions about diesel engines.

Accordingly, the National Research Council organized the Diesel Impacts Study Committee in the Assembly of Engineering, which operated in conjunction with the Assembly of Life Sciences for aspects of the study dealing with the possible adverse health effects of diesel engine emissions. The committee consisted of 20 members drawn from diverse disciplines and backgrounds--medical research, health care, environmental protection,

chemical and mechanical engineering, political science, economics, banking, and business management. Because the scope of the study involved a complex range of questions and problems, the committee established four panels to examine, respectively, the issues involving technology, environment, human health, and public policy. Each of the four panels was made up of specialists from the relevant subject of concern, as well as some members of the committee.

In performing their separate tasks the panels sometimes called on experts to assist in elucidating special matters and explicating certain problems. In the case of the study reported here, the committee chairman, Henry S. Rowen, asked Roy McDonald, at the time a graduate student at the Stanford University Graduate School of Business, and Gregory K. Ingram, an urban development economist at The World Bank, to examine the implications of the increasing use of diesel cars on traffic fatalities. (Mr. McDonald subsequently joined ARC Technologies, Inc., in Palo Alto, California.) Their work became part of the economic and policy analyses performed by the Analytic Panel for the committee's final report, Diesel Cars: Benefits, Risks, and Public Policy. To provide a wider dissemination of the complete report by McDonald and Ingram, the committee requested the National Research Council to issue the document as a supporting paper.

The National Research Council customarily publishes only the final reports of its committees--and then only after the report has been reviewed by a group other than its authors, according to procedures laid down by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. Because such a large volume of information and analysis was assembled for consideration by the committee, the reports of the Technology Panel and the Health Effects Panel are being published after peer review. In addition, three other reports by associated authors are being issued as supporting papers. Each of these has been used by the committee in developing its findings, though this supporting paper has not undergone the critical review process customary within the National Research Council.

Some conclusions implied in this report may be at variance with the conclusions of the committee's report. The findings reported in this document are those of the authors and are not necessarily endorsed by the committee or the National Research Council.

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1

INTRODUCTION AND SUMMARY

In automobiles and other motor vehicles, reducing the vehicle weight improves fuel economy. In fact, most fuel economy gains achieved for automobiles in model years 1976 through 1981 have been obtained from weight reductions rather than from power-train improvements. Unfortunately, empirical studies indicate that when vehicle weight is reduced the probability of injuries or fatalities to drivers and passengers in traffic accidents is increased. Suppose diesel engines, which are more fuel efficient than gasoline engines, were prohibited for any reason from the fleet of light-duty motor vehicles. The loss could be measured in terms of reduced fuel efficiency for the entire fleet. By holding the vehicle weight distribution constant, traffic injuries and fatalities would also be constant. Alternatively, the loss could be measured in terms of increased injuries and fatalities from traffic accidents by holding fleet fuel economy constant and thereby reducing the average vehicle weight. To put the savings from the use of diesels in terms of traffic casualties, in the 1990's when diesels are estimated to constitute perhaps as much as 25 percent of light-duty vehicle miles traveled (VMT), several hundred fewer fatalities and several thousand fewer injuries are likely to occur per year. The actual outcome could well be at an intermediate point, with some gain in fuel economy as well as some reduction in fatalities. However, the current policy has been to improve fuel economy through the Corporate Average Fuel Economy (CAFE) standards and to accept potential increases in traffic casualties that accompany vehicle "downsizing."

To estimate the loss of banning diesels in terms of traffic casualties, we used a weight-safety model that incorporated three key observations:

- The probability of an accident (per vehicle mile traveled) does not depend on vehicle weight, once such driver characteristics as age are considered. More research is needed about this subject, but the best assumption on the basis of current understanding is that accident rates are independent of vehicle weight.

- In multiple-car collisions, heavier vehicles have a decisive safety advantage when they encounter smaller cars as well as when they are involved with cars of equal weight. Collisions between two small cars are more hazardous than collisions between two large cars. The first effect follows from the momentum transfer in crashes of cars of mixed weight, when the small car decelerates faster, and the second from the lesser amount of interior space in small cars to absorb the impact and to safeguard the occupants. Two independently derived models, based on empirical data (Mela, 1974; Carlson, 1979), show comparable characterizations of this phenomenon.

- In single-vehicle and car-truck collisions, the larger car is apparently safer, but the effect is weaker and less clear than in the multiple-vehicle case.

If the safety features of passenger cars (e.g., improved bumpers, dual braking systems, head restraints) are not altered over the likely range of future vehicle sizes, a reduction in average vehicle weight of 100 pounds is estimated to increase the annual number of traffic accident fatalities by approximately 1,000. If diesel engines were not used in automobiles and all of their fuel economy advantage (assumed to be 35 percent) was balanced by weight reductions in the gasoline-powered fleet, there would be approximately 800 deaths more per year in an all gasoline fleet than in a fleet that was 10 percent diesel, and approximately 2,000 more traffic deaths per year in an all gasoline fleet than in a fleet that was 25 percent diesel.

Under certain circumstances, these projections of fatality rates could be reduced. First, the parameters of the statistical models used were estimated with data from accidents involving cars manufactured in the 1970's, and were based on the safety features of those vehicles.

Design changes in future vehicles may improve their safety, weaken the dependence of traffic casualties on vehicle weight, and reduce the incremental increase in traffic fatalities cause by downsizing. In particular, the uniform front-end crash standards to be implemented in the early 1980's should tend to reduce the safety inequality between large and small cars. It is virtually impossible to forecast the effect of such design changes, but they are not likely to remove completely the relation between vehicle weight or size and occupant safety.

Second, future safety design changes such as the introduction of passive restraint systems (e.g., automatic seat belts and air bags) could also reduce the number of collision fatalities. Although the effectiveness of future safety design changes is difficult to predict, a reduction in the level of total fatalities will proportionately reduce the safety effect calculated by the model.

Third, the projections assume that diesel fuel efficiency advantages over gasoline engines are not affected by a limitation or prohibition of diesel cars. In fact, technological advances in gasoline engines might be stimulated if diesels were ruled out, because more research and engineering resources might then be devoted to gasoline engine development. For example, if the diesel fuel economy advantage were halved, the projected increase in traffic casualties caused by eliminating diesels would only be half as large.

One factor that tends to increase the estimate is the potential of diesels for reducing fire-related automobile deaths. Fire-related fatalities are difficult to identify because death may be caused by either collision or fire. Based upon the physical properties of diesel fuel, the insurance discount allowed for diesel (as opposed to gasoline) truck fleets, and a review of state-by-state data on truck accidents, diesel vehicles appear to have a significantly lower incidence of fiery collisions. The actual savings here are likely to be real, but smaller than those for weight effects.

2

ENGINE TYPE, FUEL ECONOMY, AUTOMOBILE WEIGHT AND USE

The calculation procedure presented in this report begins by determining the forfeited fuel economy in a 1985 or 1990 auto production fleet from the replacement of all light-duty diesels with gasoline-powered automobiles of comparable performance. Next, the average weight reduction of cars in the fleet needed to recoup this forfeited fuel economy is computed using an empirically derived weight/fuel economy model.

To estimate the influence of weight reduction on automobile fatalities and injuries, we used two models derived from state-by-state accident data. Since these models require the weight distributions of the fleets before and after a prospective prohibition of diesel cars, projections were made of the percent of sales and the percent of vehicle miles traveled (VMT) in each of 21 weight classes for 1985 and 1990. This section summarizes the empirical relationship between engine type and fuel economy, and between vehicle weight and fuel economy, and also outlines the procedures used to forecast distributions of vehicle sales and vehicle miles traveled according to weight categories.

Relationship of Diesel Car Sales and Fuel Economy

Diesel-powered automobiles are more fuel efficient than gasoline-powered automobiles. If light-duty diesel vehicles are proscribed from the production fleet and those vehicles are then replaced by gasoline cars with comparable performance characteristics and similar weight, the fuel economy of the fleet will be reduced.

Defining comparable performance characteristics is difficult because the two power plants exhibit different

torque curves (torque output versus rpm), which can be only partially compensated by changes in transmission design. Generally speaking, a smaller displacement gasoline engine matches the road performance of a given diesel engine. When this is taken into account, diesels appear to obtain about 35 percent more miles per gallon than comparable gasoline cars, although this advantage may change as technology improves.

Corporate Average Fuel Economy (CAFE) is defined as a harmonic average of the fuel economies of the production fleet. The fuel economy forfeit calculation is based upon this measure of average fuel economy because the same logic supporting its use for EPA policy is appropriate here--that is, minimizing the harmonic average (but not the arithmetic average)of the fuel mileage of the production fleet will minimize the number of gallons consumed per million vehicle miles traveled (VMT).* To calculate the fuel economy forfeit, let:

FEG = Harmonically Averaged Fuel Economy of Gasoline-Powered Vehicles, mpg;

FED = Same for Diesel-Powered Vehicles;

MPD = Market Penetration of Diesels, fraction;

DPR = Fuel Economy Premium of Diesels, ratio of FED over the harmonic average of a "comparable" replacement of gasoline-powered vehicles;

CAFE = Corporate Average Fuel Economy of Mixed Gasoline/Diesel Production Fleet; and

CAFE' = Corporate Average Fuel Economy of Replacement All-Gasoline Production Fleet.

*This holds as long as miles per car is not correlated with fuel economy, as has been true historically.

Then,

$$(2.1) \qquad CAFE = \frac{1}{\frac{1-MPD}{FEG} + \frac{MPD}{FED}}$$

and

$$(2.2) \qquad CAFE' = \frac{1}{\frac{1-MPD}{FEG} + \frac{(MPD)\ (DPR)}{FED}}$$

Equations 2.1 and 2.2 determine the value CAFE-CAFE', which is the fuel economy forfeit implied by a prohibition of diesel production. The forfeit is sensitive to the inputs DPR, MPD, CAFE, FED, and FEG. Therefore, the result will depend upon whether diesels are predominantly used in big cars ("big diesels") or small cars ("small diesels"). The sensitivity of the result to the size of the affected cars is measured by assuming that the diesel fuel economy is either 25 mpg ("big diesel") or 30 mpg ("small diesel"). CAFE is assumed to be 27.5 miles per gallon. Calculations illustrating the sensitivity of the fuel economy forfeit to the parameters are displayed in Table 1.

Relationship of Automobile Weight and CAFE

Lighter cars achieve better gasoline mileage than heavier cars. In response to a fuel economy forfeit caused by the prohibition of diesel production, car makers are likely to recoup some of the loss by trimming the production fleet weight. The relation between fuel economy measured in miles per gallon (mpg) and vehicle inertial weight (IW) measured in pounds can be represented by

$$(2.3) \qquad mpg \times e^{(m \times IW)} = K$$

where m and K are parameters and e is the natural log base. Values of K and m estimated for average gasoline, best gasoline, and best diesel vehicles in model year 1980 are listed in Table 2, which also displays the estimated miles per gallon for the three cases at selected inertia weights.

Alternatively, two studies (EPA, 1977, and SAE, 1978) based upon EPA test data have supported the model.

TABLE 1: FUEL ECONOMY FORFEIT

CAFE-CAFE' as a Function of MPD, DPR, and FED		
MPD	DPR=1.25	DPR=1.40
"Big Diesels"		FED = 25
0.05	0.37	0.59
0.10	0.74	1.16
0.25	1.77	2.73
"Small Diesels"		FED = 30
0.05	0.31	0.50
0.10	0.62	0.97
0.25	1.49	2.31

(2.4) $$\frac{1}{FC} = FE \times IW$$

where FE = fuel economy; FC = fuel consumption constant, gallons/mile-lb; and IW = inertia weight, lb. The EPA study determined that FC^{-1} (1/FC) had remained remarkably constant at about 50,000 from 1957 to 1973. By 1978, according to the second study, FC^{-1} had risen to 71,000. This change gives an estimate of the rate of fuel economy improvement not associated with weight reduction. By using the production scenario developed in the next section, allowing for expected variations among auto makers, and assuming that the production fleet fuel economy is 27.5 mpg, the portion of improved fuel economy due to weight reduction from 1975 to 1985 is between 40 and 50 percent. This unitary elastic* model checks reasonably well with the former model and is more

*Unitary elastic signifies that a 1 percent decrease in IW produces a 1 percent increase in FE.

TABLE 2: EQUATION 2.1 PARAMETERS AND FUEL ECONOMIES

Case	Parameters m	K	MPG at Weights of 2000	3000	4000
Average Gas	0.000326	64.52	33.6	24.3	17.5
Best Gas	0.000368	89.29	42.8	29.6	20.5
Best Diesel	0.000280	83.33	47.6	36.0	27.2

analytically tractable for the purposes of this calculation, so we have used it in our calculations.

Because of the functional form of equation 2.4, the amount of weight reduction required to regain a given level of lost fuel economy depends upon the values of FC and the CAFE standard. Moreover, with equation 2.4 the CAFE is inversely proportional to the arithmetic mean weight of the production fleet, and it is not sensitive to the distribution of the weight reduction.

Table 3 exhibits examples of calculations of the relation between the required weight reduction and the fuel economy forfeit caused by limiting diesels. For 1985, desired CAFE fuel economy is assumed to be 27.5 mpg. For 1990 three cases are shown: 32.5 mpg, 35.0 mpg, and 37.5 mpg. These correspond to increases in FC^{-1} from 1985 to 1990 equal to 0.05, 0.58, and 1.12 of the increases of FC^{-1} from 1980 to 1985 respectively. Given past trends in the value of FC^{-1}, a value of 35 mpg, or slightly higher, appears to be a good forecast for 1990 model year fuel economy. (The introduction of electric vehicles, which are not considered in this analysis because of their relatively low expected penetration by 1990, could alter the results, since electric vehicles will achieve fuel efficiencies as high as 185 mpg. For the purposes of this analysis, they can be overlooked.)

Vehicle Miles Traveled by Weight and Year

Although the relation between fuel economy and vehicle weight is independent of the distribution of vehicles across weight classes, this independence does

TABLE 3: AUTOMOBILE WEIGHT AND FUEL ECONOMY

Weight Reduction Requirement versus CAFE and Fuel Economy Forfeit

Year	CAFE (MPG)	Fuel Economy Loss, mpg	Required Weight Reduction, lb[a]
1985	27.5	1	97
1985	27.5	2	188
1985	27.5	5	426
1990	35.0	1	65
1990	35.0	2	127
1990	35.0	5	294
1990	32.5	5	314
1990	37.5	5	277

[a]Assumes all fuel economy loss is made up by weight reduction. Results are linear with the actual fraction used; if, for example, 1985 fuel economy loss is 2 mpg and 50 percent is to be made up through weight reduction, 97 pounds is the required weight reduction.

not hold for the relation between traffic casualties and vehicle weight. Before describing the models relating traffic casualties and weight, the method of projecting the weight distribution of vehicles on the road in the year of interest is summarized. The vehicle miles traveled (VMT) for each weight class is taken to be the appropriate measure of exposure to accidents. It is assumed that frequency of accidents per car is not a function of weight. (This critical assumption is discussed in section IV). Also, although VMT per car is a weak function of the vehicle's weight, this adjustment was not made. (This relationship is also discussed in section IV.)

The first step in the analysis was to develop a profile of production figures by weight class for 1970, 1975, 1980, 1985, and 1990. The figures for 1970 and 1975 represent rough averages of the intervals 1969-1971 and 1974-1976 respectively, since they are used as end points for interpolations of 1970-1975 and 1975-1980. The use of a single year's production figures might have biased the results because of single year production anomalies. Extrapolations for 1980, 1985, and 1990 were based on a report (Corp-Tech Planning, 1978) that projected weight trends for domestic passenger automobiles through 1986. Adjustments were made to include imports, which significantly decreased the expected annual change for the smaller cars:

Automobile Weight Class	Corp-Tech Annual Change[a]	Composite Annual Change Used[a]
Full	142	140
Medium	121	100
Compact	116	80
Mini and Subcompact	70	40

[a]Pounds trimmed per vehicle

Although the market shares of the four size classes of cars--full, medium, compact, and subcompact--have been fairly stable from 1975 to 1980, a slight shift to smaller sizes was assumed. The market share changes per year were assumed to be:

Full	-0.5%
Medium	-0.3%
Compact	+0.3%
Subcompact	+0.5%

Table A.1 in the Appendix shows the resulting profiles. Although speculative, the weight-trend profiles capture the two dominant changes anticipated through 1990. First, the average new car will become much lighter, from 3,200 pounds in 1980 to about 2,350 pounds in 1990. Second, the spread of weights will be narrowed, because more weight will be trimmed from large cars than from small ones.

Using the weight profile of new cars, projections of sales volume, and scrappage rates of existing cars, the distribution of the entire fleet by weight category and age was projected for 1985 and 1990. The distribution of VMT by auto age was then combined with the fleet composition projections to produce the percent VMT by weight class for 1975, 1980, 1985, and 1990 shown in Appendix Table A.2. The values in parentheses represent the percent VMT in that weight class by cars equipped with mandatory passive restraints. The values are based upon the assumption that full size cars are so equipped in 1982; medium in 1983; and compact and subcompact sizes in 1984. The percent VMT distributions generated in this manner and shown in Appendix Table A.2 for 1985 and 1990 are for the "standard" weight projection.

"Revised" weight projections were computed by altering the sales assumptions from Table A.1 and generating new VMT profiles for Appendix Tables A.3, A.4, A.5, and A.6. For Table A.3 the 1985 column in Table A.1 was altered to allow for a fixed amount of additional weight reduction in model year 1985. "Standard" (S) is the result with no additional weight reduction; S-50 is the profile if 50 pounds is removed from all 1985 cars; S-100 if 100 pounds is removed from all 1985 cars; and S-200 if 200 pounds is removed from all 1985 cars. Car weight was not allowed to fall below 1,400 pounds, however. For Table A.4 the additional assumption was made that more weight would be removed each successive year from 1985 to 1990 to make up for the potential increased market share of diesels. S-50 thus assumes removal of 50 pounds in 1985, 50 more in 1986, etc., until a total of 300 extra pounds had been trimmed by 1990. Table A.5 presents the revised weight distributions for 1990, assuming a one-time weight reduction in 1985 is carried through to 1990. Table A.6 presents the Big Car Only scenarios. Here S-100, Big Car Only, means that 200 pounds was removed from the heavy half of the cars and no weight was removed from the other half. The 1990 scenario assumes this practice annually for the six years, 1985 to 1990. The "standard" and "revised" scenarios provide a wide range of weight distributions for analysis.

3

AUTOMOBILE WEIGHT AND SAFETY

Automobile weight has been shown to be an important variable in determining the casualty outcome of traffic accidents. The relationship is most clearly demonstrated in the case of two-car collisons. (See Carlson, 1979; Dutt and Reinfurt, 1977; Fatal Accident Reporting System Report, 1978; Mela, 1974; O'Neill, Ginsburg and Robinson, 1977; O'Neill, Joksch and Haddon, 1974; NHTSA, 1979 Traffic Fatalities, 1980; and Stewart and Stutts, 1978). There is some evidence (Mayyasi et al, 1974) that there is an effect in car-truck and single-car accidents as well, although these relationships are not as strong. Finally, there is some speculation that pedestrian fatalities are linked with automobile weight (Mayyasi), which suggests that auto weight might also be a factor in collisions with bicycles and motorcyles.

In the later cases, the geometry of the striking (or struck) vehicle is important, and in many crashes the "second collision" subsequent to rebound from the car does much of the damage to the pedestrian or cyclist. In addition, since the reduced mass of the car-pedestrian or car-cyclist system is approximately that of the pedestrian or cyclist, the momentum transfer is virtually independent of the vehicle mass.

In the following subsections, evaluations of each of these collision types are presented in turn. In a later subsection the literature supporting the models is discussed. Finally, the underlying assumptions used in this analysis are evaluated in sample calculations discussed later in this section.

Two-Car Collisions

The outcome of a two-car collision is dependent upon weight for two reasons. First, a weight differential between the two vehicles results in an unequal momentum transfer. The occupant of the lighter vehicle suffers a more severe deceleration. Second, weight is closely correlated with size, so the lighter vehicle is generally smaller, affording the occupant less protection in a crash with another vehicle and more bodily impact with components in the interior of the occupant's car.

Two models have been used to estimate the sensitivity of two-car fatalities and severe injuries to changes in the fleet weight mix. The first of the two models (Mela, 1974) provides as a relative risk measure the probability of fatalities and injuries in a collision between two vehicles of specified weights. It similarly provides these measures for single-vehicle accidents as a function of vehicle weight. A total haz rd index for a given weight mix is computed by calculating the probability of a crash between vehicles in each of the 21 weight categories and summing the 21 x 21 risk factors, while accounting for the probability of a crash in each of the 441 possible weight combinations. The single-vehicle problem is handled in the same manner.

The second of the two models (Carlson, 1979) is more difficult to implement, but has advantages. It controls for more variables, such as vehicle speed and driver age, and is based upon more recent data. This model also has been implemented using the matrix of possible accidents based on 21 weight categories. The good correspondence between the results of the two models suggests that the computations based upon the exponential model (Mela, 1974) will be reasonably accurate.

1. Exponential Model

The exponential model (Mela, 1974) predicts fatalities in two-car collisions will scale at:

$$F \propto (K)(0.93)^{W_1}(1.02)^{W_2}$$

where W_1 and W_2 are the weights of the subject car and the other car respectively in hundreds of pounds. For serious injuries this relationship becomes:

$$I \propto (K)(0.95)^{W_1}(1.02)^{W_2}$$

Let W_i be the weight of the average car in weight class i of our 21 classes. And let $VMT_i(A)$ be the percent of VMT traveled by weight class i in scenario A. The relative risk of fatality in scenario A compared to the risk in 1975 is then:

$$\frac{\sum_{i=1}^{21}\sum_{j=1}^{21} VMT_i(A)VMT_j(A)(0.93^{Wi})(1.02^{Wj})}{\sum_{i=1}^{21}\sum_{j=1}^{21} VMT_i(1975)VMT_j(1975)(0.93^{Wi})(1.02^{Wj})}$$

These indices are contained in Tables 4 and 5. The first entry in Table 4 indicates that for the same number of accidents in 1975 and 1985 there would be 1.385 times as many fatalities in 1985 if passive restraints are no more effective than voluntary safety belt usage in 1975 and if VMT in 1985 equals VMT in 1975. ("Voluntary usage" means a large number of nonusers and a small number of users of lap and shoulder belts.) The second S entry indicates that this factor drops to 1.068 if passive restraints are 100 percent effective (resulting in no casualties) in 50 percent of the cases and as effective as voluntary usage during 1975 in the other 50 percent.

In both 1985 and 1990 the Big Car Only scenarios are less hazardous than the S-100 scenario, so evenly applied weight reduction produces a worse case. In fact, because manufacturers are unlikely to decrease the weight of small cars rather than large cars, it represents a worst-case scenario.

Such factors may be adjusted by some predicted increase in the number of accidents from 1975 to 1985. The number of two-car fatalities has grown approximately 1.6 percent per year from 1965 to 1973, and, after dropping dramatically from 1973 to 1974, has grown at about 2.2 percent per year from 1974 to 1977.* Using a

*The drop in fatalities from 1973 to 1974 seems to be attributable to the imposition of 55 mph speed limits and the reduction in driving due to the oil crisis.

TABLE 4: EXPONENTIAL MODEL RESULTS, 1985

Two-Car Collisions, Fatal

Scenario	Passive Restraint Effectiveness (%)			
	0	50	70	90
S	1.385	1.068	0.942	0.815
S-50	1.394	1.072	0.944	0.815
S-100, BCO	1.395	1.072	0.943	0.814
S-100	1.403	1.076	0.946	0.815
S-200	1.417	1.083	0.949	0.815

Two-Car Collisions, Serious Injury

Scenario	Passive Restraint Effectiveness (%)			
	0	50	70	90
S	1.223	0.944	0.833	0.721
S-50	1.228	0.946	0.833	0.721
S-100, BCO	1.229	0.946	0.833	0.720
S-100	1.232	0.948	0.834	0.720
S-200	1.240	0.951	0.835	0.719

Legend:
- S = Standard cars, weight changes as in Table A.2
- S-50 = Standard weight, minus 50 pounds, removed
- S-100, BCO = Standard weight cars, except 200 pounds trimmed from big cars only.
- S-100 = Standard weight, minus 100 pounds, removed.
- S-200 = Standard weight, minus 200 pounds, removed.

NR = No-ramp Case, Table A.5

TABLE 5: EXPONENTIAL MODEL RESULTS, 1990

Two-Car Collisions, Fatal

Scenario[a]	Passive Restraint Effectiveness (%) 0	50	70	90
S	1.653	0.921	0.629	0.336
S-50	1.802	0.993	0.670	0.346
S-100, BCO	1.918	--	--	--
S-100	1.942	1.061	0.708	0.356
S-200	2.184	1.177	0.774	0.371
S-50, NR	1.669	0.925	0.627	0.330
S-100, NR	1.731	0.968	0.662	0.357
S-200, NR	1.782	1.000	0.686	0.374

Two-Car Collisions, Serious Injury

Scenario	Passive Restraint Effectiveness (%) 0	50	70	90
S	1.363	0.762	0.521	0.281
S-50	1.435	0.796	0.540	0.284
S-100, BCO	1.492	--	--	--
S-100	1.502	0.827	0.557	0.287
S-200	1.616	0.880	0.585	0.291
S-50, NR	1.365	0.759	0.516	0.274
S-100, NR	1.405	0.788	0.541	0.294
S-200, NR	1.426	0.802	0.553	0.303

[a]See legend from table 4

growth rate of 2 percent yields growth factors from 1975 of 1.22 for 1985 and 1.35 for 1990. This 2 percent growth rate is obviously uncertain, given the recent discontinuities in accident trends.

2. Crash Injury Prediction Model

The Crash Injury Prediction Model (Carlson, 1979) is more elaborate and difficult to apply than the exponential model because it controls not only for weight but also vehicle speed, occupant age, and occupant seat location. A rigorous application of this model would require as inputs multivariate distributions for the independent variables--the distribution of driver age as a function of speed of collision, seating position, car weight, and "other car" weight all would have to be known. A simplifying assumption, which has been shown by Carlson to predict results of existing data bases well, is to use a median age and seating distribution. For this analysis an intermediate level of sophistication was used. Age distributions, speed distributions, seating distributions, and weight distributions were assumed to be independent and such univariate distributions were used. The same occupant age distribution was used for 1985 and 1990, although the actual age distribution of car occupants in 1990 would tend to increase the casualties predicted by the Crash Injury Prediction Model. Hence, the 1990 results will slightly understate casualties.

The model predicts a value for an accident severity index, Y, based upon observed parameters. Then the values Z_1, probability of death, and Z_2, probability of severe injury, can be calculated by a bounded quadratic function of Y. The value Y is predicted as a linear function of variables from four classes: age; the categorical variable D and R_f for occupant in driver's seat and occupant in right front seat; W_5 - W_8, categorical variables for subject car weight classes; and ΔV_1, the change in vehicle velocity. ΔV_1 is defined as:

$$\Delta V_1 = \frac{W_2}{W_1 + W_2}\sqrt{(V_1^2 + V_2^2 + 2V_1V_2\cos\alpha)}$$

where W_1 is the weight of the subject car, W_2 is the weight of the other car, V_1 is the speed of the subject

car, V_2 is the speed of the other car, and α is the closing angle of the accident. Y is predicted by separate models for occupants with and without seat belts.

Relative risk indices for this model were developed in the same manner as for the exponential model. The same passive restraint effectiveness definitions were used, but passive restraints were evaluated only at zero and 70 percent effectiveness. To account for increases in VMT, Crash Injury Prediction Model factors can also be adjusted to reflect expected accident incidence growth at the rate of 2 percent per year, but VMT has been assumed constant in the calculations here.

The results are shown in Tables 6 and 7. The predictions agree with the results in Tables 4 and 5 from the exponential model in form but show higher sensitivity of casualty levels to weights. The indices are generally higher than those calculated from the exponential model and are more sensitive to weight trimming. Combined, these two factors produce a 100 percent higher prediction of casualty increase per pound of weight not lost in 1985 than that calculated from the exponential model, and a 75 percent higher prediction for the 1990 scenarios.

Both the Crash Injury Prediction Model and the exponential model predict that the Big Car Only scenarios (where 200 pounds of weight trim occurs in the heavier half of the cars and no trim is made in the other cars--equivalent to a 100-pound reduction throughout the fleet in its effect on average fleet weight) are less hazardous than a policy of reducing the weight of all cars. Trimming 100 pounds off the average car in the production fleet by a Big Car Only strategy appears to be only about as hazardous as a reduction of 50 to 80 pounds of weight in every production car.

The Crash Injury Prediction Model contains separate weight parameters to model the hostile effect of increasing weight to the "other car" and its protective effect to the occupant; thus, there are a few scenarios where a weight trim decreases the index slightly. These scenarios generally consist of extreme weight reductions where a lower bound of 1,400 pounds arbitrarily placed on the weight distributions (in Appendix Table A.4) had a strong effect upon the outcome by reducing variance of the distribution; these conditions suggest that the nonmonotonic outcomes shown should be disregarded.

This sort of nonmonotonicity occurs less frequently in the exponential model. The functional form of the exponential model implies that, in collisons between cars

TABLE 6: CRASH INJURY PREDICTION MODEL, 1985

Two-Car, Fatal

Scenario[a]	Passive Restraint Effectiveness (%)	
	0	70
S	1.443	0.990
S-50	1.462	0.993
S-100, BCO	1.448	0.984
S-100	1.481	0.995
S-200	1.513	0.999

Two-Car, Serious Injury

Scenario	Passive Restraint Effectiveness (%)	
	0	70
S	1.351	0.918
S-50	1.361	0.918
S-100, BCO	1.362	0.916
S-100	1.371	0.919
S-200	1.386	0.920

[a]See legend from Table 4

TABLE 7: CRASH INJURY PREDICTION MODEL, 1980

Two-Car, Fatal

Scenario[a]	Passive Restraint Effectiveness (%)	
	0	70
S	1.631	0.608
S-50	1.883	0.670
S-100, BCO	1.926	--
S-100	2.037	0.702
S-200	2.014	0.666
S-50, NR	1.672	0.618
S-100, NR	1.740	0.654
S-200, NR	1.804	0.683

Two-Car, Serious Injury

Scenario	Passive Restraint Effectiveness (%)	
	0	70
S	1.556	0.587
S-50	1.688	0.616
S-100, BCO	1.763	--
S-100	1.791	0.635
S-200	1.878	0.644
S-50, NR	1.571	0.586
S-100, NR	1.622	0.615
S-200, NR	1.659	0.633

[a]See legend from Table 4

of more than about 1,000 pounds difference, reducing the weight of the heavier car decreases the total probability of an accompanying fatality. Such collisions are becoming less frequent as the weight variance diminishes within the fleet.

Although the results from the Crash Injury Prediction Model check well with those from the exponential model and control for more factors, the exponential model is used as the base for our computations. The exponential model provides results that are more plausible in terms of monotonic response to parametric changes in weight trimming.

Single-Vehicle and Car-Truck Collisions

The relationship between automobile weight and casualties in single-vehicle accidents is not as well determined as that for two-car accidents. Because single-car accidents are usually collisions with fixed objects, or noncollision accidents, the momentum transfer argument does not apply. Still, the size-weight correlation implies some added protection for bigger, heavier cars. The exponential model predicts for serious and fatal accidents combined:

$$(F + I) \propto K(0.98)^{W_1}$$

where W_1 is, as before, the weight of the car in hundreds of pounds.

Table 8 contains the relative-risk indices calculated from this model in the same manner as those obtained for two-car crashes. Note that the results are intensely sensitive to the effectiveness of passive restraint, but not to the distribution of weight removal. S-100 and S-100, BCO, are virtually the same.

Car-truck collisions resemble single-vehicle accidents since the truck is virtually a fixed object to the colliding car, and truck occupant fatalities in such crashes are very rare. The variance of collision speeds is probably much higher, though, because a substantial number of head-on and rear-end crashes of this type occur, while most single-vehicle crashes occur as head-on collisions with stationary objects or as events involving rollover.

TABLE 8: SINGLE-CAR FATALITY AND INJURY, 1985-1990

1985

Single Car, Serious and Fatal Combined

Scenario[a]	Passive Restraint Effectiveness (%)			
	0	50	70	90
S	1.151	0.892	0.789	0.685
S-50	1.154	0.893	0.789	0.685
S-100, BCO	1.156	0.894	0.790	0.685
S-100	1.156	0.895	0.790	0.685
S-200	1.160	0.897	0.791	0.686

1990

Single Car, Serious and Fatal Combined

Scenario	Passive Restraint Effectiveness (%)			
	0	50	70	90
S	1.253	0.074	0.484	0.264
S-50	1.291	0.723	0.496	0.268
S-100, BCO	1.330	--	--	--
S-100	1.330	0.742	0.507	0.272
S-200	1.406	0.780	0.530	0.280

[a]See legend from Table 4

However, analyzing the serious injury and fatality results for car-truck crashes presented by O'Neill et al. (1974), suggests a good fit with the form:

$$I \propto 0.97^{W}$$

and Stewart et al. (1978) recommends a model of the form:

$$I \propto 0.95^{W}$$

Fatality rates are at least as sensitive to weight as serious injuries in all the other models. Thus a conservative assumption is to use:

$$I \propto 0.98^{W}$$
$$F \propto 0.98^{W}$$

Accidents Involving Pedestrians, Many Vehicles, and Fire

Single-car, car-truck, and two-car accidents account for approximately 65 percent of the annual traffic fatality toll. The remaining 35 percent is made up of accident types that are expected to be no more than minimally affected by a weight shift in automobile production.

A brief analysis of pedestrian accident patterns indicates that pedestrian fatalities will be reduced by a very small amount if car weights are trimmed. In the 1980's the annual pedestrian fatality rate is likely to approach 10,000 per year.

About 10 percent of fatal accidents involve 3 or more passenger cars. These were accounted for by combining those collisions with the two-car, mid-1970 base figure and treating them as two-car crashes.

Fire is estimated to be responsible for deaths in as many as 1.5 percent of all fatal traffic accidents but may well be much less common (Cooley, 1975). This proportion is very difficult to determine reliably because it is generally not known if occupants who died in such vehicles were alive when the fire started. Diesel fuel, which is less volatile than gasoline, may reduce the number of fire deaths in traffic accidents. Since about 30,000 deaths occur annually in passenger cars, pickups, and vans, the total elimination of automobile fires might save as many as 450 lives (1.5 percent of 30,000). There are reportedly about 700,000

accidents per year in which fuel is spilled (Siegel and Namm, 1970) and 90,000 accidents per year in which a fire erupts. If 450 fatalities is a good estimate, then one in 2,000 of such fires causes a death.

Presumably some diesel fires will occur, particularly following collisions of gasoline vehicles with diesel vehicles. Also, the number of fire fatalities reduced by using diesels will scale roughly with the portion of the fleet using diesel fuel. When the diesel car market reaches 25 percent, a fatality reduction of 100 might be a plausible (but very uncertain) estimate.

Mid-1970's Accident Casualties

Table 9 shows typical levels of accident casualties for single- and two-car accidents in the mid-1970's. The relative risk indices will be used to scale these values to predict 1985 and 1990 casualties and marginal casualties caused by weight shifts.

The fatality numbers are estimated from the Fatal Accident Reporting System data and include such casualties in cars, pickups, and vans. These do not total to the familiar statistic of 50,000 deaths because they exclude fatalities involving pedicycles, motorcycles, buses, and trucks, as well as pedestrian fatalities. The latter values are not expected to be substantially affected by a shift in the light-duty vehicle weight mix.

The values in Table 9 for single-car and car-truck injuries are extrapolated, based on the ratio of total injuries to fatalities in single-car and car-truck collisions and the profiles of fatalities, serious injuries, and moderate injuries in multicar accidents. Single-car and car-truck accidents cause substantially more fatalities per accident than multiple-car accidents.

The models of weight/safety dependence generally do not attempt to estimate such a relationship for moderate injuries. The effect in moderate injury cases is likely to be smaller than that for more serious casualties because there is a strong weight dependence for fatalities, a weaker one for serious injuries, and (apparently) none for no-injury accidents (since these account for the bulk of accidents and no significant weight dependence has been demonstrated for incidence of accidents). Although accidents involving moderate injuries are less damaging and costly than those

TABLE 9: MID-1970's ANNUAL ACCIDENT CASUALTIES[a]

Type of Collision/Accident	Fatalities	Serious Injuries	Moderate Injuries
Single-Car	14,000	32,000	230,000
Two-Car	11,500	73,600	640,000
Car-Truck	3,800	8,700	63,000
Total	29,300	114,300	933,000

[a]Sources: Accident Facts (1980), which gives total injuries by accident category; and Carlson (1979), which provides the ratio of serious injuries to fatalities in multicar crashes, but does not give such a ratio for single-car crashes or car-truck collisions. Data are aggregates of more detailed categories shown in Accident Facts and are estimated averages of 1974-76 experience.

involving fatalities or serious injuries, they are more common. On balance, the effect of a weight change on moderate injuries is not inconsequential. In making the case that weight reduction increases traffic casualties, ignoring moderate injury statistics is a conservative omission.

Sample Calculations

- If diesel sales in 1985 are projected at 10 percent and diesels are the big cars on the road, a federal prohibition of diesel cars would require an increase in the CAFE standard of between 0.74 and 1.16 mpg (see Table 1), depending upon the assumed fuel efficiency advantage of diesels over gasoline cars. For calculation purposes, use 0.95 for the CAFE loss to be made up.
- Assume all of the estimated loss is made up by weight changes. Then, the weight reduction is about 90 pounds per car in 1985. But suppose diesel sales in 1990 come to 25 percent. Then, according to equations 2.11

and 2.12, 2.8 mpg must be made up in weight reduction, representing about 170 pounds per car.

* Using the exponential model and assuming 50 percent passive restraint effectiveness, the risk index differences for 1985 are:

Two-Car, Fatal	(0.9)(1.076 - 1.068) = 0.007
Two-Car, Serious	(0.9)(0.948 - 0.944) = 0.004
One-Car, Fatal or Serious	(0.9)(0.895) - 0.892) = 0.003

* These factors could be scaled up using a 1.22 multiplier to account for growth in VMT, but the assumption here is that VMT is constant. Multiplying by the figures in Table 9 gives totals for 1985 of:

	Fatalities	Serious Injuries
Single-Car and Car-Truck	53	122
Two-Car	81	294
TOTAL	134	416

* For 1990, interpolation between scenarios is necessary, and the results are as follows:

	Fatalities	Serious Injuries
Single-Car and Car-Truck	409	936
Two-Car	932	3,165
TOTAL	1,341	4,101

For the calculations employed in the report of the Diesel Impacts Study Committee (NRC, 1981) fatality estimates such as those above were not directly employed. What was needed instead were estimates of the number of person-years of expected lives lost per pound reduction in the fleet average weight for each of three cases evaluated. The estimates were calculated from information provided in this paper as follows.

The procedure begins with the calculation of the average fleet weight (weighted by VMT) from the data in Table A.2. For 1975, 1985, and 1990 the average weights are 3,802, 3,091, and 2,651, respectively. These weights are combined with the zero restraint effectiveness factors (scenario S) from Tables 4, 5, and 8 and the baseline fatalities in Table 9 as shown in Table 10. The calculations show that with no increase in accidents, the number of fatalities will rise by about 10 per each pound

TABLE 10: BASE CALCULATIONS

	YEAR		
	1975	1985	1990
Fatality Risk index			
Single car	1.0	1.151	1.253
Two car	1.0	1.385	1.653
Car-truck	1.0	1.151	1.253
Fatalities			
Single car	14,000[a]	16,114	17,542
Two car	11,500[a]	15,928	19,010
Car-truck	3,800[a]	4,374	4,761
Total	29,300[a]	36,416	41,313
Δ Fatality	-	7116	12,013
Δ Weight	-	711	1151
Fatality/lb.		10.0	10.4

[a]1974-76 averages from Table 9.

of average fleet-weight reduction. If the number of accidents increases over time, these factors will scale proportionally. Moreover, if passive restraint systems are introduced and they are effective at reducing the base number of fatalities, this factor will be scaled down proportionally.

To calculate factors for case C in the Diesel Impacts Study, the worst case for auto casualties, we assume that restraints are not introduced (effectiveness = 0) and that 1975 base accidents increase by 35 percent by 1995. In addition, we assume that an auto death reduces years lived by 42.* Then 10 x 1.35 x 42 = 567 person-years per pound. We round this to 600 for case C.

*Average life expectancy in the United States is 73 years and the average age of persons who die in traffic accidents is 31. The difference in these two numbers is 42.

For case B in the Diesel Impacts Study, the intermediate case, we assume that restraints reduce fatalities by one-third, that accidents increase by 10 percent by 1995 and that an auto death reduces years lived by 42. Then 10 x 1.1 x 42 x .66 = 305 person-years per pound. This is rounded to 300 for case B.

For case A in the Diesel Impacts Study, the best case for auto casualties, we assume that restraints reduce fatalities by two-thirds, that accidents increase by 10 percent by 1995, and that an auto death reduces years lived by 42. Then 10 x 1.1 x 42 x .33 = 152 person-years per pound, which is rounded to 150 for scenario A.

One approximate rule of thumb can be deduced from the numbers in Table 10. In the mid-1980's the average weight of vehicles is approximately 3,000 pounds. A 1 percent reduction in average weight (about 30 pounds) causes an additional 300 weight-related fatalities, which is approximately a 1 percent increase (300 is 1 percent of 30,000) of such facilities. Hence, in approximate terms, a 1 percent reduction in average vehicle weight produces a 1 percent increase in weight-related fatalities in the mid-1980's. Moreover, as shown in Equation 2.4, a 1 percent reduction in average auto weight also produces a 1 percent increase in fuel economy.

4

MODELS USED AND CRITICAL ASSUMPTIONS

Because an excellent literature review on the subject of automobile weight and automobile safety is available elsewhere (Stewart and Stutts, 1978), this section describes the principal models used in our assessment and some of the critical assumptions of our analysis.

Models

The domestic weight projections are based upon a comprehensive analysis (Corp-Tech Planning, 1978) by make and model of anticipated design changes through 1986. Given the long lead time for design introductions in the automobile industry, the projections are likely to be quite accurate.

The exponential model of traffic casualties (Mela, 1974), which is really the core of the analyses reported here, suffers from two major problems. First, it was derived from data compiled in New York State alone; second, the data were for the years 1969 to 1971. Regarding the first problem, Hans Joksch tested the model against more recent data from North Carolina. Within the precision of coefficients stated in this paper, he obtained the same result. To verify the applicability of the formula to still more recent collision data, an analysis of the relevant data (NHTSA, 1979 Traffic Fatalities) was conducted. The Fatal Accident Reporting System report expressed the ratio of fatalities in size class X vehicles to those in size class Y vehicles in class X-class Y collisions:

	Compact	Mid-Size	Full Size
Subcompact	3.4	6.3	8.2
Compact		1.9	2.3
Midsize			1.3

These ratios imply a set of weight differences between the classes if they are to conform with the exponential model. Thus, if R_{ij} is the ratio for class i versus class j, we have:

$$\frac{(0.93^{Wi})(1.02^{Wj})}{0.93^{Wj})(1.02^{Wi})} = Rij$$

which reduces to:

$$W_2 - W_1 = \frac{\text{Log } R_{ij}}{\text{Log } 1.097}$$

This provides means for three verification tests of the formula, because one would expect, for example, to see

[Weight(Midsize) - Weight(Subcompact)] - [Weight(Compact) - Weight(Subcompact)] = [Weight(Midsize) - Weight(Compact)]

Performing the three available consistency checks and computing the ratios of the anticipated equal-weight differences gives the three values 1.04, 1.01, and 1.06--close to unity. The actual weight differential roughly matches those given in the Corp-Tech report, except that the computed weight difference between compact and subcompact cars is very large (1,300 pounds). The formula may be somewhat erroneous in this weight category because few subcompacts were represented in the data base used for its derivation. The direction of the presumed error indicates a tendency for the model to produce results that underestimate the weight disadvantage of small cars; it is thus a conservative approximation.

The Crash Injury Prediction Model is based upon an extensive, relatively recent national data base and is, hence, more appropriate for trend projections in the 1980's. The statistical validity of this model is also much more carefully documented than for the exponential model. The major fault of the Crash Injury Prediction Model is that it is based upon data that may have substantial reporting errors, especially in the dominant factor ΔV_1, the velocity. The covariance of the

input parameters (e.g., age and car weight) was ignored in the analysis, so a more careful study would be recommended before indices computed from this model might be used as the bases for casualty projections.

Critical Assumptions

Numerous assumptions burden a forecast of this sort. The following discussion deals with only five assumptions:

1. Accident rates are not correlated with weight. This continues to be a controversial issue because it is difficult to construct a comprehensive accident data base. While fatal accidents are adequately catalogued in the Fatal Accident Reporting System, the problem of unreported nonfatal accidents remains. Data from the Highway Loss Data Institute indicate no systematic dependence of insurance claim frequency based on automobile weight, but the existence of deductibles in insurance policies, in any event, would undermine the completeness of this data base.

The preponderance of relevant literature holds that when appropriate allowances are made for other factors, such as age and alcohol consumption of the driver, no significant correlation can be found for accident rates and vehicle weights. Given this conclusion, even if a weak relationship is surmised, it would probably be obscured by the dependence of fatalities per accident on vehicle weights.

2. Size and weight are correlated. This has historically been true. Given the economic pressures to build the lightest possible cars with fairly substantial interior space (or some other measure of buyer preference), auto makers will be unlikely to build an extra-heavy car of any given size category. The fuel price pressure is likely to augment, rather than diminish, this correlation.

3. Fatalities per accident are affected only by weight distribution. It could reasonably be argued that the observed dependence on weight for road casualties actually results from other correlated variables such as bumper to firewall distance, interior space, handling stability, and bumper height. But, to the extent that these factors continue to correlate with weight in the future, this is not a problem. Not merely weight alone, but weight and all the design parameters that go along with weight, influences the number of casualties.

Of course, other external factors affect the casualty rate as well. Driver and environmental characteristics are the two main categories. The most important driver characteristics are age and alcohol use. Regarding age, it appears that younger drivers are involved in more dangerous accidents (higher speed, more single-car accidents), and older drivers are less able to survive a given level of crash stress. These two factors tend to offset one another, although the younger driver is overall at greater risk. Because older drivers tend to drive the heavier cars, a Big Car Only weight-trimming strategy would seem to add risk to older drivers. Because of their diminished ability to survive crashes, older drivers also appear to be more sensitive to the weight/safety relationship than younger drivers (Stewart and Stutts, 1978). Alcohol is a major factor in fatal accidents, but this is less likely than age to produce a bias in the preceding results.

Regarding environmental factors, one would expect that, with weight shifts accounted for, total fatalities per VMT would be declining due to safety improvements in both roads and automobiles. This effect is difficult to measure because of the anomalous drop in casualties in 1973 (attributed to the enactment of the 55 mph speed limit), but a slight decrease in fatalities per VMT appears to be occurring. If true, this trend also would reduce by a small amount the overall accident casualty projections for the 1980's and would proportionally reduce the marginal results caused by weight shifts.

4. Future automobile fleets will resemble those upon which the models are based. The NHTSA Research Safety Vehicle program has demonstrated the feasibility of building a substantially safer small car, possibly at an economical price. However, the current financial condition of the U.S. automobile industry, combined with the long lead times necessary for design changes, suggests that major safety improvements (with the exception of passive restraints) are not likely to be forthcoming. Moreover, the expected improvements in braking and side impact protection will simply raise the safety of all automobiles and seem unlikely to shift safety balances between large cars and small cars. This has apparently been the case in the 1970's, as demonstrated by the Fatal Accident Reporting System data analyzed in assumption 3.

The proposed Standard 208 regulations for occupant restraints are likely to induce improvements in the relative safety of small cars, especially for small cars

in single-vehicle crashes. However, the extent of this change is unpredictable. In the short run, the delay between the application of passive restraint requirements in large cars and small cars and the "stock effect" of older cars on the road not subject to Standard 208 will partly offset this new consideration; a long-run projection would be mere speculation at this time. Standard 208 and similar safety standards will also reduce the expected safety effects for cases in foregoing models to the extent that they diminish total fatalities. Since fatality rate reductions in the relevant collisions categories could range from 50 to 90 percent (as modeled by the "passive restraint effectiveness" sensitivity analysis), this could be very important. Still, the fate of Standard 208 is undecided. Recent congressional action, the general financial situation in the U.S. automobile industry, the failure to enact similar legislation in 1973, and the potential for motorists to disconnect automatic seat belts all suggest difficulties in imposing Standard 208.

In the late 1970's, smaller cars were increasingly equipped with front-wheel drive. This major technological change may improve their safety relative to larger cars by changing the "force stroke" (or crush) characteristics of the front end. Unfortunately, it takes several years for a technological innovation to achieve sufficient market penetration to be evaluated and reported, so the importance of this development is not yet known.

5. VMT is not correlated with weight. Dutt and Reinfurt (1977) studied this relationship and found a slight dependency of VMT on weight, particularly as cars age. Compared to full-size cars, small cars are driven about 10 percent fewer miles per year in their first five years and as much as 20 percent more miles per year in their eleventh to fifteenth years. This effect is clearly very dependent upon user costs, and the small impact it would have on the foregoing calculations does not justify the level of analysis that would be required to account for such a shift.

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APPENDIX

Weight Classes and Weight Distributions of Vehicles

TABLE A.1: WEIGHT CLASS, SALES

Vehicle Sales, U.S., by Year and Weight Class, Percent

Wt., Pounds	1970	1975	1980	1985	1990
1400-1600	0.0	0.0	0.9	3.5	9.7
1600-1800	0.0	0.9	3.6	4.5	10.5
1800-2000	2.0	2.6	3.5	7.4	10.8
2000-2200	3.0	3.5	5.1	6.0	11.4
2200-2400	3.0	3.1	6.9	7.9	11.0
2400-2600	4.0	2.8	5.6	5.8	9.0
2600-2800	4.0	4.3	7.3	12.7	12.1
2800-3000	4.0	5.2	6.7	14.3	9.7
3000-3200	4.0	5.9	8.2	15.6	8.8
3200-3400	5.0	4.8	8.1	7.6	7.0
3400-3600	6.0	4.5	10.4	5.3	0.0
3600-3800	7.0	7.8	11.4	3.1	0.0
3800-4000	8.0	8.2	7.4	2.5	0.0
4000-4200	12.0	10.5	5.2	2.8	0.0
4200-4400	10.0	7.6	4.2	1.0	0.0
4400-4600	10.0	8.0	3.1	0.0	0.0
4600-4800	8.0	7.6	2.4	0.0	0.0
4800-5000	6.0	3.3	0.0	0.0	0.0
5000-5200	3.0	3.1	0.0	0.0	0.0
5200-5400	1.0	1.5	0.0	0.0	0.0
5400-5600	0.0	4.8	0.0	0.0	0.0
Average:	3812	3791	3180	2770	2358

TABLE A.2: VMT BY WEIGHT AND YEAR

Percent VMT by Weight Class

Wt., Pounds	Year 1975	1980	1985	1990
1400-1600	0	0.4	1.9(1.0)	5.8(5.4)
1600-1800	0.4	1.9	3.6(1.4)	6.9(6.2)
1800-2000	2.3	2.9	5.0(2.2)	8.3(7.4)
2000-2200	3.2	4.1	5.3(1.9)	8.2(7.2)
2200-2400	3.0	4.7	6.8(2.9)	9.1(7.9)
2400-2600	3.5	4.2	5.3(1.8)	7.1(6.0)
2600-2800	4.1	5.5	9.2(5.2)	11.7(10.6)
2800-3000	4.5	5.7	9.7(5.7)	11.3(10.2)
3000-3200	4.8	6.6	11.0(6.3)	11.6(10.4)
3200-3400	4.9	6.2	7.4(3.4)	7.4(6.4)
3400-3600	5.4	7.2	7.4(3.7)	3.8(3.0)
3600-3800	7.3	9.2	7.4(2.9)	3.0(2.2)
3800-4000	8.1	7.8	5.4(2.1)	2.1(1.6)
4000-4200	11.4	8.5	4.9(1.9)	2.0(1.6)
4200-4400	9.0	6.5	3.3(1.0)	1.0(0.7)
4400-4600	9.2	6.2	2.5(0.5)	0.4(0.25)
4600-4800	7.8	5.4	2.1(0.4)	0.3(0.2)
4800-5000	4.9	2.3	0.5(0.0)	0.0(0.0)
5000-5200	3.0	1.8	0.4(0.0)	0.0(0.0)
5200-5400	1.2	0.8	0.2(0.0)	0.0(0.0)
5400-5600	2.0	2.1	0.7(0.0)	0.0(0.0)

These forecasts are for the "standard" weight projection.

TABLE A.3: REVISED WEIGHT DISTRIBUTIONS 1985

	1985, VMT %			
Wt., Pounds	Standard	S-50	S-100	S-200
1400-1600	1.9 (1.0)	2.1 (1.2)	2.3 (1.4)	2.7 (1.8)
1600-1800	3.6 (1.4)	3.7 (1.5)	3.9 (1.7)	4.1 (1.9)
1800-2000	5.0 (2.2)	5.0 (2.2)	4.9 (2.1)	4.8 (2.0)
2000-2200	5.3 (1.9)	5.4 (2.0)	5.5 (2.1)	5.6 (2.2)
2200-2400	6.8 (2.9)	6.7 (2.8)	6.6 (2.7)	6.4 (2.5)
2400-2600	5.3 (1.8)	5.6 (2.1)	5.9 (2.4)	6.5 (3.0)
2600-2800	9.2 (5.2)	9.3 (5.3)	9.4 (5.4)	9.5 (5.5)
2800-3000	9.7 (5.7)	9.8 (5.8)	9.8 (5.8)	9.9 (5.9)
3000-3200	11.0 (6.3)	10.6 (5.9)	10.3 (5.6)	9.6 (4.9)
3200-3400	7.4 (3.4)	7.3 (3.3)	7.2 (3.2)	7.0 (3.0)
3400-3600	7.4 (3.7)	7.3 (3.6)	7.2 (3.5)	7.0 (3.3)
3600-3800	7.4 (2.9)	7.3 (2.8)	7.3 (2.8)	7.3 (2.8)
3800-4000	5.4 (2.1)	5.4 (2.1)	5.4 (2.1)	5.5 (2.2)
4000-4200	4.9 (1.9)	4.8 (1.8)	4.7 (1.7)	4.6 (1.6)
4200-4400	3.3 (1.0)	3.3 (1.0)	3.2 (0.9)	3.1 (0.8)
4400-4600	2.5 (0.5)	2.5 (0.5)	2.5 (0.5)	2.5 (0.5)
4600-4800	2.5 (0.4)	2.1 (0.4)	2.1 (0.4)	2.1 (0.4)
4800-5000	0.5 (0.0)	0.5 (0.0)	0.5 (0.0)	0.5 (0.0)
5000-5200	0.4 (0.0)	0.4 (0.0)	0.4 (0.0)	0.4 (0.0)
5200-5400	0.2 (0.0)	0.2 (0.0)	0.2 (0.0)	0.2 (0.0)
5400-5600	0.7 (0.0)	0.7 (0.0)	0.7 (0.0)	0.7 (0.0)

Assumes 50, 100, or 200 pounds are removed from model year 1985 cars relative to "standard" weight projection.

TABLE A.4: REVISED WEIGHT DISTRIBUTIONS, 1990

	1990, VMT %			
Wt., Pounds	Standard	S-50	S-100	S-200
1400-1600	5.8 (5.4)	12.1 (11.7)	18.4 (18.0)	31.0 (30.6)
1600-1800	6.9 (6.2)	9.7 (9.0)	12.5 (11.8)	18.1 (17.4)
1800-2000	8.3 (7.4)	8.1 (7.2)	7.9 (7.0)	7.5 (6.6)
2000-2200	8.2 (7.4)	9.8 (8.8)	11.4 (10.4)	9.6 (8.6)
2200-2400	9.1 (7.9)	6.7 (5.5)	4.3 (3.1)	9.5 (8.3)
2400-2600	7.1 (6.0)	8.2 (7.1)	9.3 (8.2)	6.0 (4.9)
2600-2800	11.7(10.6)	9.9 (8.8)	8.1 (7.0)	4.5 (3.4)
2800-3000	11.3(10.2)	10.0 (8.9)	8.7 (7.6)	5.1 (4.0)
3000-3200	11.6(10.4)	8.6 (7.4)	5.6 (4.4)	1.4 (0.2)
3200-3400	7.4 (6.4)	5.5 (4.5)	3.6 (2.6)	1.2 (0.2)
3400-3600	3.8 (3.0)	3.4 (2.6)	3.0 (2.2)	1.0 (0.2)
3600-3800	3.0 (2.2)	2.6 (1.8)	2.2 (1.4)	0.9 (0.1)
3800-4000	2.1 (1.6)	2.1 (1.6)	2.1 (1.6)	2.1 (1.6)
4000-4200	2.0 (1.6)	1.6 (1.2)	1.2 (0.8)	0.4 (0.0)
4200-4400	1.0 (0.7)	1.0 (0.7)	1.0 (0.7)	1.0 (0.7)
4400-4600	0.4 (0.25)	0.4 (0.25)	0.4 (0.25)	0.4 (0.25)
4600-4800	0.3 (0.2)	0.3 (0.2)	0.3 (0.2)	0.3 (0.2)
4800-5000	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
5000-5200	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
5200-5400	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
5400-5600	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)

Assumes 50, 100, and 200 pound increments are removed successively in each model year from 1985 to 1990. The weight difference from the standard projection becomes cumulatively larger from 1985 to 1990.

TABLE A.5: REVISED WEIGHT DISTRIBUTIONS, @ 1990, NO RAMP*

Wt., Pounds	Standard	S-50, NR*	S-100, NR*	S-200, NR*
1400-1600	5.8 (5.4)	7.3 (6.7)	8.8 (7.9)	11.8 (10.4)
1600-1800	6.9 (6.2)	7.2 (6.5)	7.4 (6.7)	7.9 (7.2)
1800-2000	8.3 (7.4)	8.3 (7.4)	8.2 (7.3)	8.1 (7.2)
2000-2200	8.2 (7.2)	8.3 (7.3)	8.4 (7.4)	8.6 (7.6)
2200-2400	9.1 (7.9)	8.0 (7.5)	8.4 (7.2)	7.6 (6.4)
2400-2600	7.1 (6.0)	8.0 (6.9)	8.9 (7.8)	10.6 (9.5)
2600-2800	11.7(10.6)	11.6(10.5)	11.5 (10.4)	11.2 (10.1)
2800-3000	11.7(10.2)	11.3(10.2)	11.3 (10.2)	11.3 (10.2)
3000-3200	11.6(10.4)	10.8 (9.6)	10.0 (8.8)	8.3 (7.1)
3200-3400	7.4 (6.4)	6.5 (5.5)	5.6 (4.6)	3.7 (2.7)
3400-3600	3.8 (3.0)	3.6 (2.8)	3.5 (2.7)	3.1 (2.3)
3600-3800	3.0 (2.2)	3.0 (2.2)	2.9 (2.1)	2.8 (2.0)
3800-4000	2.1 (1.6)	2.1 (1.6)	2.2 (1.7)	2.2 (1.7)
4000-4200	2.0 (1.6)	1.9 (1.5)	1.7 (1.3)	1.4 (1.0)
4200-4400	1.0 (0.7)	0.9 (0.6)	0.9 (0.6)	0.7 (0.4)
4400-4600	0.4 (0.25)	0.4 (0.25)	0.4 (0.25)	0.4 (0.25)
4600-4800	0.3 (0.2)	0.3 (0.2)	0.3 (0.2)	0.3 (0.2)
4800-5000	-----	----	----	0.0 (0.0)
5000-5200	-----	----	----	0.0 (0.0)
5200-5400	-----	----	----	0.0 (0.0)
5400-5600	-----	----	---	0.0 (0.0)

Assumes 50, 100, and 200 pounds are removed in model year 1985 and that this constant difference from the standard projection is maintained from 1985-1990.

TABLE A.6: REVISED WEIGHT DISTRIBUTIONS, BIG CAR ONLY @ 1985-1990

Wt., Pounds	1985, VMT S-100, BCO	1990, VMT S-100, BCO
1400-1600	1.9 (1.0)	14.3
1600-1800	3.6 (1.4)	13.0
1800-2000	5.0 (2.2)	12.5
2000-2200	5.3 (1.9)	8.2
2200-2400	6.8 (2.9)	7.8
2400-2600	5.3 (1.8)	3.8
2600-2800	11.7 (7.7)	17.1
2800-3000	9.9 (5.9)	8.4
3000-3200	9.6 (4.9)	2.7
3200-3400	7.0 (3.0)	3.2
3400-3600	7.0 (3.3)	2.2
3600-3800	7.3 (2.8)	2.6
3800-4000	5.5 (2.2)	2.5
4000-4200	4.6 (1.6)	0.8
4200-4400	3.2 (0.8)	0.2
4400-4600	2.4 (0.5)	0.4
4600-4800	2.1 (0.4)	0.3
4800-5000	0.5 (0.0)	0.0
5000-5200	0.4 (0.0)	0.0
5200-5400	0.2 (0.0)	0.0
5400-5600	0.7 (0.0)	0.0

Assumes 200 pounds removed in 1985 and therefore (cumulatively) from the heaviest half of the fleet only.